Thunderstorm Persistence at Cape Kennedy, Florida

NASA Report 67-4

TECHNICAL MEMORANDUM X-

THUNDERSTORM PERSISTENCE AT CAPE KENNEDY, FLORIDA

prepared by

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ABSTRACT

A study is made of thunderstorm occurrence and persistence at Cape Kennedy, Florida, during the period January 1957 through December 1962. Hourly and special observations are considered.

Occurrence is noted by:

1. Each hour of the day
2. Four-hour periods of the day
3. Eight-hour overlapping periods of the day
4. The 24-hour period 0000E - 2359E

Persistence is counted from the first day of the sequence to the final day. The longest sequence encountered in the 8-hour groupings is 12 days. In the single hour groupings the longest sequence is 7 days.

Application of two models to this problem is discussed. Chi-Square and Kolmogorov-Smirnov tests are used to test the applicability and to choose the better model.

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THUNDERSTORM PERSISTENCE AT CAPE KENNEDY, FLORIDA

I. Introduction

The continuing evaluation of meteorological data affecting aerospace operations at Cape Kennedy, Florida is needed. The probability of thunderstorm occurrences at Cape Kennedy is available in the Summary of Monthly Aerological Records (SMAR) format for each month. This summary was prepared for the National Aeronautics and Space Administration by the National Weather Records Center in Asheville, North Carolina. Further study is now needed on the conditional probability of thunderstorm occurrences.

II. Statement of the Problem

The initial question to be answered is, "What is the empirical probability of a thunderstorm occurring at Cape Kennedy, Florida during a given month or season for a specified time interval?"

The thunderstorm persistency question may also be explored by changing the time period from 1 hour to 4 and 8 hours. Given that one thunderstorm has occurred at Cape Kennedy during a specified time period in a given month or season, what is the empirical conditional probability of one occurrence the following day in the same time period? What are the empirical conditional probabilities of thunderstorm occurrences on the next 2, 3,..., k days, given 1, 2,..., i consecutive days of thunderstorm occurrences during the same time period?

After grouping the data in 24-hour or daily periods the questions are asked: "What are the frequencies of thunderstorm occurrences by month or season? What are the empirical conditional probabilities of thunderstorm occurrences for the daily periods?"

The occurrence of a thunderstorm is frequently accompanied by high surface winds and lightning. High surface wind is one of the critical meteorological parameters concerning space vehicle ground operations. Thus information is needed concerning the frequency of thunderstorm winds near the surface.

III. Source of Data

The Surface Weather Observation Record (WBAN 10-A and B) for station 12868, Cape Kennedy, Florida is the data source. All observations for the period of record are included in the tabulation of thunderstorm occurrences at Cape Kennedy. Each day is taken as beginning at 0000 EST and ending at 2359 EST. January 1957 through December 1962 is the period of record for this report. The weather observing procedural definition is: "A thunderstorm is reported whenever thunder is heard at the station within the past 15 minutes." [1] A reasonable upper limit for the audibility of thunder is 10-15 miles. [2, 3]

IV. Data Extraction

The tables are prepared in the following manner. Observations for each month of the 6 years of record are tallied in tables A1.1 through A1.12 in the form of the number of occurrences of sequences of thunderstorms of exactly 1 day, 2 days,..., 7 days. Only one occurrence is tallied per time period. If a thunderstorm occurs on the last day of the month, the record of the first day of the following month is searched. If a thunderstorm occurred, it is tallied as a part of the sequences in the preceding month, and the next day is checked. This operation is continued until the end of the run is found. The N-count (total number of observations) for the months involved are adjusted accordingly. Thus, a run of 5 days may be found from June 28 through July 2. In this case, a run of 5 days would be entered

for June with an N-count of 32 days and the N-count for July would be adjusted to 29 days. Table A1.13 contains the empirical probabilities of an occurrence (f) of a thunderstorm by hour, by month. These values are computed by dividing the total number of occurrences ($\bar{f}$) in each time period by the N-count ($f = F/N$). Tables A1.14 through A1.17 are seasonal tallies of the number of occurrences of sequences of thunderstorms of exactly 1 day, 2 days,..., 7 days. Table A1.18 contains the empirical probabilities of an occurrence (f) of a thunderstorm by hour and by season.

Tables A2.1 through A2.11 contain the tallied number of occurrences (F_j) of thunderstorm sequences of exactly 1 day, 2 days,..., 12 days per 4-hour, 8-hour, and 24-hour (daily) periods by month and season. The frequencies (F) of exactly j days are used to obtain the number of occurrences (M) of sequences of the given length (i). These values are computed by the equation:

$$M_i = \sum_{j=i}^{n} [(j-i+1)(F_j)]$$

where n is the length in days of the longest sequence of thunderstorm occurrences.

Tables A3.1 through A3.15 show the empirical conditional probabilities (p) of at least k additional consecutive days with thunderstorms occurring within the stated periods, given that at least i prior consecutive days have occurred. The empirical probability (f) of at least k consecutive days is indicated by i=0. These tables are derived by the equation $p(k|i) = M_{k+i}/M_k$.

Table A4.1, Frequency Distribution of Maximum Wind Speeds Observed with Thunderstorms at Cape Kennedy, 1957-1962, is obtained by examining the

record for every day on which a thunderstorm was reported. One maximum wind speed value from hourly or special observation, from remarks or summary of the day is tallied for each day of a thunderstorm occurrence. Circular N states [1], "In general, observed wind speeds are a 1-minute average, but may also be a 5-minute average or the fastest mile, when the speed is determined from recording equipment." The reports of station location and instrumentation (AWS Form 70) for the period 1957 through 1962 list two wind sensing and recording systems: An AN/GMQ-1A, located on the roof of an inflation shelter 36 feet above ground with an Esterline Angus graphic recorder, and a Friez Aerovane, located on the roof of an inflation shelter 34 feet above ground with a Friez recorder, Model 141-5. There were periods of dual instrumentation.

According to Circular N [op. cit.], "Gustiness is characterized by sudden intermittent increases in speed, with at least 9 knots variation between peaks and lulls. ...The peak gust is the speed of the highest gust from the recorder charts during the 24 hours ending at midnight EST." Wind speed values obtained from these criteria are the sources of maximum wind speeds observed with thunderstorms. In the event no gust was recorded, the highest reported wind speed within 30 minutes of the thunderstorm was used.

V. Discussion of Data

Tables of empirical conditional probabilities of sequences of thunderstorm occurrences by specified time periods are presented in the Appendix, tables A3.1 through A3.15. These tables are best explained by giving two related examples.

Example 1

What is the empirical probability of a thunderstorm occurrence in

June between 1200 and 1559 EST? Table A3.4 is referred to in the Appendix. On the line i=0 (given no previous occurrences), under k=1 (what is the probability of 1 additional occurrence), a probability of .333 is found.

Example 2

What is the empirical conditional probability of two additional consecutive days of thunderstorm occurrences, given that one thunderstorm has occurred in the summer between 1200 and 1959 EST? Table A3.13, on the line i=1, and under k=2, provides a conditional probability of .393.

The comparison of observed frequencies of thunderstorm occurrences with theoretical distributions is the next step in the discussion of data. The two models selected are the "Persistence Series" and the "Markov Chain Model." According to Brooks and Carruthers [4], following Eggenberger and Polya [5], the "Persistence Series" is defined as:

$$\frac{1}{(1+d')^{m/d'}}, \frac{m}{1!\,(1+d')^{m/d'+1}}, \frac{m(m+d')}{2!\,(1+d')^{m/d'+2}}, \ldots, \frac{m(m+d')(m+2d')\ldots(m+[i-1]d')}{i!\,(i+d')^{m/d'+i}}$$

where m is the mean of the observed series and $d' = \sigma^2/m - 1$. The ratio σ^2/m is termed the persistence factor.

The "Markov Chain Model" of the order 0, 1, or 2 can be used to describe sequences of time-correlated weather phenomena [7]. The zero Markov model is constructed assuming that the probability of a thunderstorm occurrence on a given day is independent of any previous occurrences. Thus if the probability of a thunderstorm occurring on a certain day is .400, then the probability of a thunderstorm occurring on two days in succession is .400 X .400 = .160. The probability of a sequence of three days with thunderstorms

would be $(.400)^3 = .064$. Thus, assuming a zero order Markov model, the probability of a sequence of thunderstorms ($\overline{T}$) of n occurrences counting from any given day is $p_n = [p(T)]^n$.

The first order Markov model is based on the assumption that the probability of an occurrence of an event (thunder) given the occurrence of the event the previous day is constant, i.e., the occurrence of the event today is independent of any occurrence before yesterday. The probability of a thunderstorm is denoted by $[p(T)]$ and the probability of a thunderstorm given that a thunderstorm has occurred on the previous day is $p(T|T)$. The probability of two consecutive days of thunder, counting from any given day, is given by the equation: $p_2 = p(T) \cdot p(T|T)$. Thus $p_n = p(T) \cdot [p(T|T)]^{n-1}$.

The second order Markov model takes into account the two previous events, assuming that today's event is independent of any event before two days ago. The equation for the second order Markov is a logical extension of the first order: $p_n = p(T) \cdot p(T|T) \cdot [p(T|TT)]^{n-2}$ for $n \geq 2$, where $p(T|TT)$ is the probability of a thunderstorm occurrence, given an occurrence during each of the two preceeding days.

The order of dependence of the Markov model that provides the best representation of thunderstorm sequences can be determined by use of the asymptotically Chi-square statistic.

The null hypothesis to be tested is that, under the assumption that the process is Markovian, the order of dependence of the occurrence of days with thunder is 0, 1 or 2 (see Appendix B for description of test). The results of the Chi-square test are shown on Table 1.1.

Table 1.1

Results of the Chi-square test to determine which order of the Markov model applies assuming the distribution is Markovian

	Zero Order	First Order	Second Order
June	23.68453**	8.36120	3.11543
July	39.56622**	5.41721	4.57970
August	21.21101**	4.59896	4.30371
Summer	76.39713**	9.82338	6.18184
df	7	6	4

** Indicates significance at the 1 percent level.

Table 1.2

The Observed and Theoretical Probability Distributions of at least the Given Number of Days at Cape Kennedy, Florida (1957-1962)

	Length of Sequences in Days											
	1	2	3	4	5	6	7	8	9	10	11	12
1200-1959 EST	June											
Observed	.402	.229	.134	.073	.034	.017	.006					
Persistence Series	.407	.253	.139	.069	.031	.012	.004					
Zero Order Markov	.402	.162	.065	.026	.011	.004	.002					
First Order Markov	.402	.229	.130	.074	.042	.024	.014					
Second Order Markov	.402	.229	.134	.078	.046	.027	.016					
1200-1959 EST	July											
Observed	.480	.342	.248	.183	.134	.099	.069	.050	.030	.020	.010	.005
Persistence Series	.462	.341	.244	.168	.113	.074	.046	.029	.016	.008	.003	.001
Zero Order Markov	.480	.231	.111	.053	.026	.012	.006	.003	.001	.001	.000	.000
First Order Markov	.480	.342	.243	.173	.123	.087	.062	.044	.031	.022	.016	.011
Second Order Markov	.480	.342	.248	.179	.130	.094	.068	.049	.036	.026	.019	.014
1200-1959 EST	August											
Observed	.374	.195	.103	.057	.029	.011						
Persistence Series	.371	.214	.105	.043	.008	.003						
Zero Order Markov	.374	.140	.052	.019	.007	.003						
First Order Markov	.374	.195	.102	.053	.028	.015						
Second Order Markov	.374	.195	.103	.055	.029	.015						
1200-1959 EST	Summer											
Observed	.422	.259	.166	.108	.068	.045	.027	.018	.011	.007	.004	.002
Persistence Series	.418	.281	.178	.107	.062	.035	.019	.010	.005	.002	.001	.000
Zero Order Markov	.422	.178	.075	.032	.013	.006	.002	.001	.000	.000	.000	.000
First Order Markov	.422	.259	.160	.098	.060	.037	.023	.014	.009	.005	.003	.002
Second Order Markov	.422	.259	.166	.106	.068	.043	.028	.018	.011	.007	.005	.003

Table 1.3

The Application of the Kolmogorov-Smirnov Test to the Maximum Differences of the Cumulative Distribution of Sequences of Thunderstorm Occurrences

	June	July	Aug.	Summer
Persistence Series	.060	.052	.055	.056
Zero Order Markov	.171	.284	.149	.215
First Order Markov	.022	.024	.011	.023
Second Order	.031	.018	.007	.005
N=Count	72	97	65	234
α = 0.20	.126	.109	.133	.076

Null hypothesis: The distribution of thunderstorm sequences occurs according to the indicated theoretical distributions.

All cases of the Zero Order Markov model are rejected.

The four theoretical probability distributions are compared with the observed probability distributions of thunderstorm sequences in table 1.2 for June, July, August, and Summer (1200 - 1959 EST). The "Kolmogorov-Smirnov" test [6] is employed to test goodness of fit. The null hypothesis is that the distribution of thunderstorm sequences is represented by the theoretical distributions discussed above. The results of this test are shown in table 1.3. In each case, the null hypothesis for the zero order Markov model is rejected at the $\alpha = 0.20$ level. We then conclude that either the "Persistence Series," the first, or second order Markov model is an acceptable representation of the observed data. Although the second order model is better than the first order as shown by the results of the Chi-square test in table 1.1, its superiority is not sufficient to warrant the additional time and effort required for its use. The first order Markov model is a better representation of the observed data than the "Persistence Series" as shown by the results of the "Kolmogorov-Smirnov" test in table 1.2. The first order Markov model, being the best representation of the observed data, is graphically displayed with the observed data in figures 1, 2, 3, and 4 for the periods June, July, August, and Summer (1200-1959 EST).

Figure 1

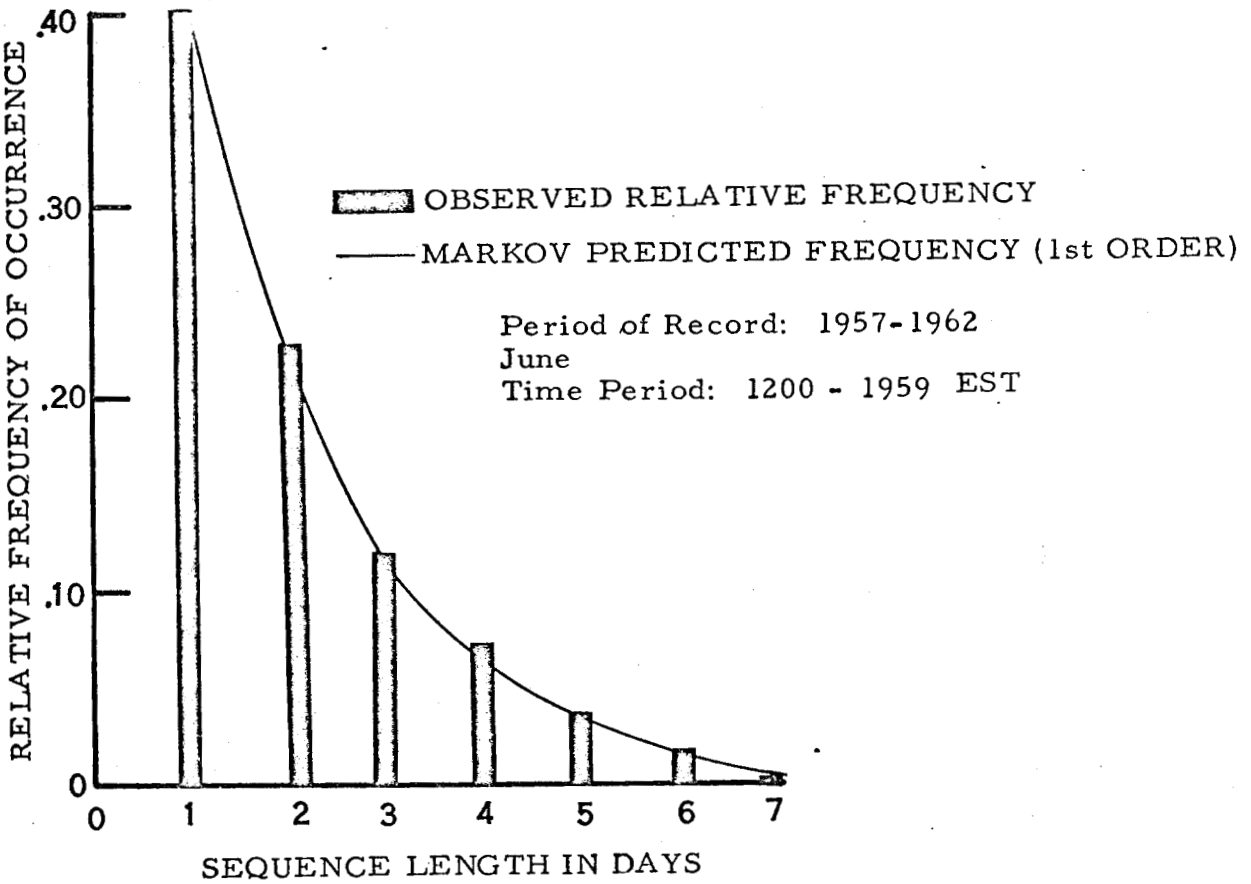

RELATIVE FREQUENCY OF OCCURRENCE
.40
.30
.20
.10
0
0
1
2
3
4
5
6
7
SEQUENCE LENGTH IN DAYS
OBSERVED RELATIVE FREQUENCY
MARKOV PREDICTED FREQUENCY (1st ORDER)
Period of Record: 1957-1962
June
Time Period: 1200 - 1959 EST

Figure 2

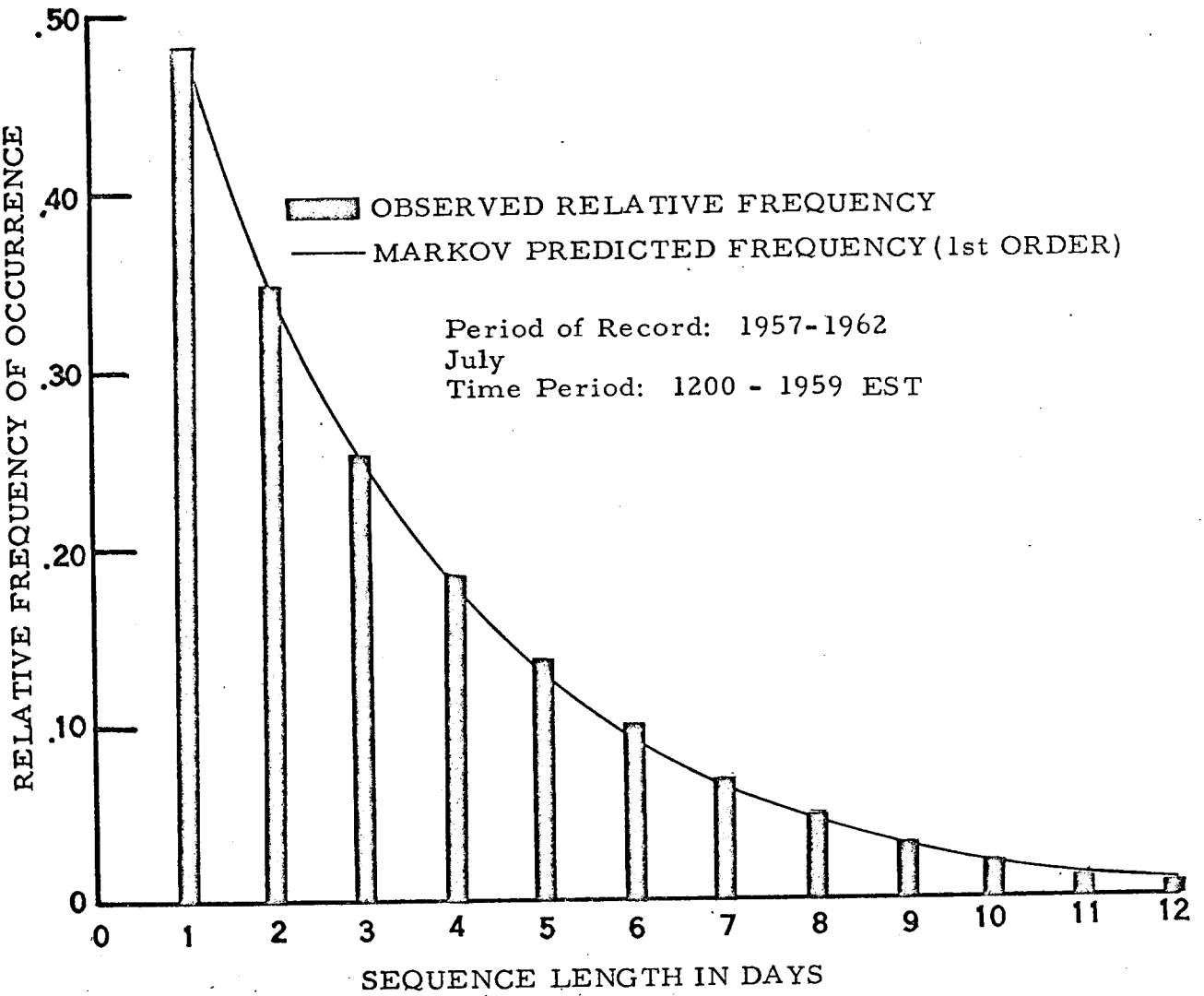

.50
.40
.30
.20
.10
0
RELATIVE FREQUENCY OF OCCURRENCE
OBSERVED RELATIVE FREQUENCY
MARKOV PREDICTED FREQUENCY (1st ORDER)
Period of Record: 1957-1962
July
Time Period: 1200 - 1959 EST
0 1 2 3 4 5 6 7 8 9 10 11 12
SEQUENCE LENGTH IN DAYS

Figure 3

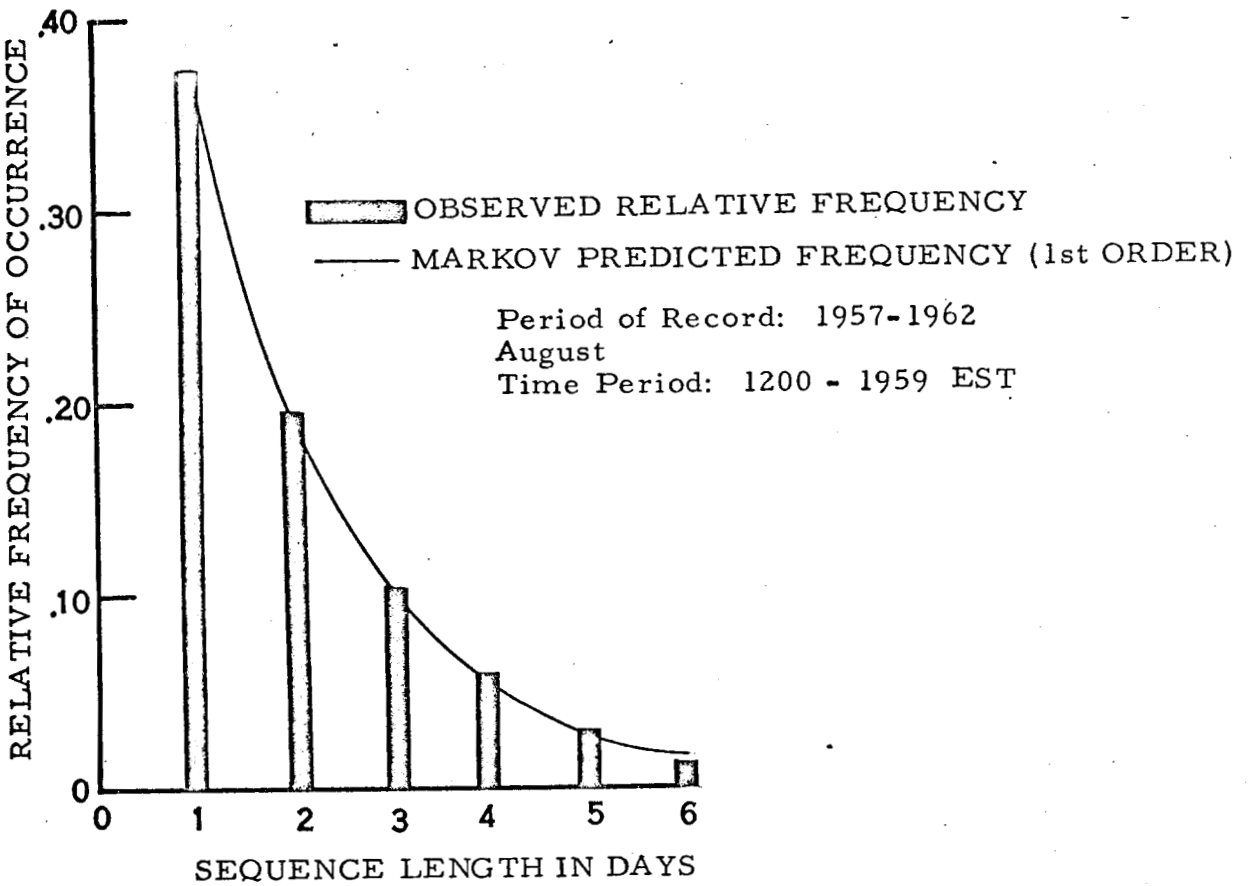
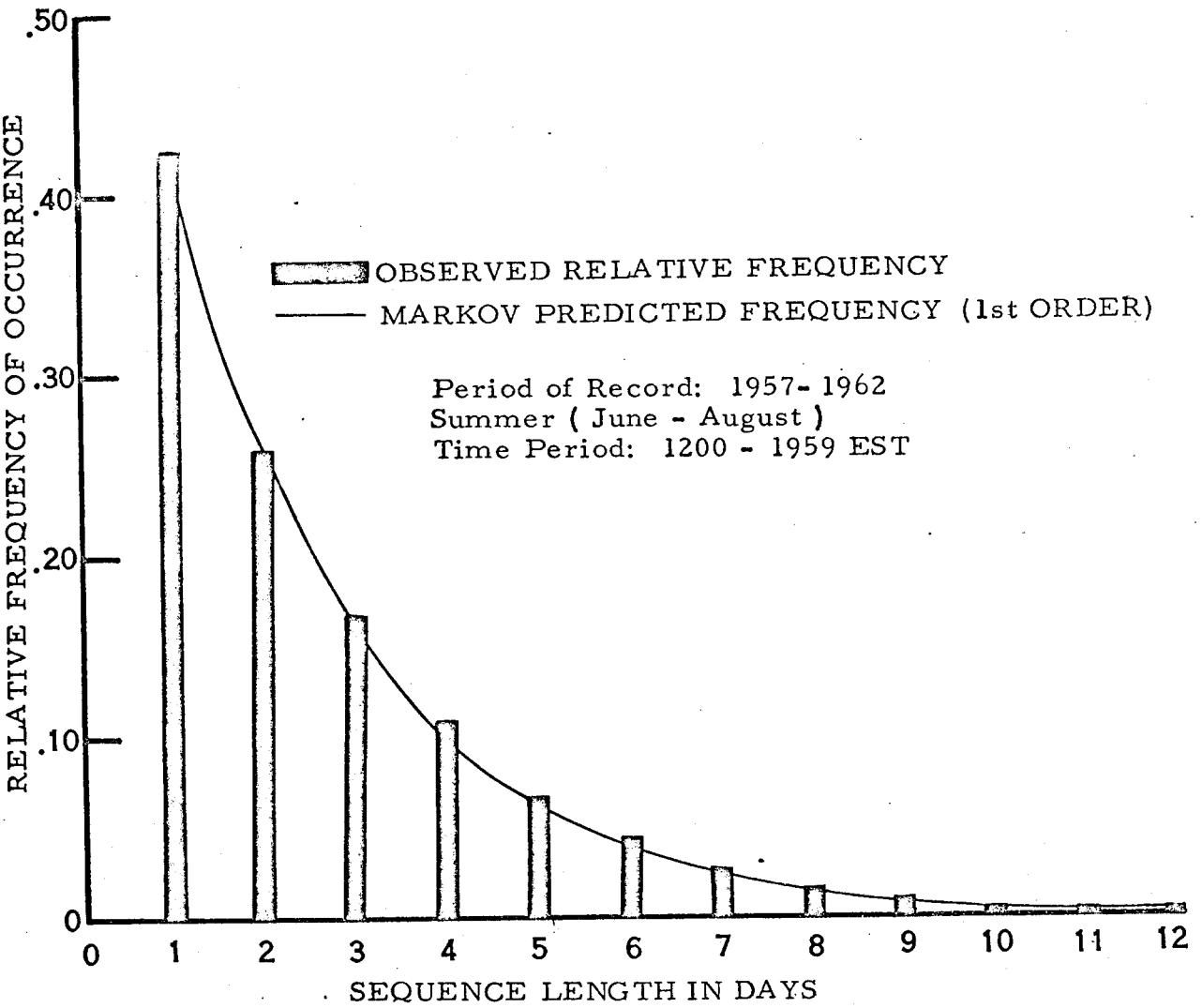

.40
.30
.20
.10
0
RELATIVE FREQUENCY OF OCCURRENCE
OBSERVED RELATIVE FREQUENCY
MARKOV PREDICTED FREQUENCY (1st ORDER)
Period of Record: 1957-1962
August
Time Period: 1200 - 1959 EST
0 1 2 3 4 5 6
SEQUENCE LENGTH IN DAYS

Figure 4


.50
.40
.30
.20
.10
0
RELATIVE FREQUENCY OF OCCURRENCE
OBSERVED RELATIVE FREQUENCY
MARKOV PREDICTED FREQUENCY (1st ORDER)
Period of Record: 1957- 1962
Summer (June - August)
Time Period: 1200 - 1959 EST
0 1 2 3 4 5 6 7 8 9 10 11 12
SEQUENCE LENGTH IN DAYS

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A P P E N D I X A

Table A1.1

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

January

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000									
0100									
0200									
0300									
0400	1							1	186
0500									
0600									
0700									
0800	1							1	186
0900	1							1	186
1000									
1100									
1200									
1300									
1400									
1500									
1600									
1700									
1800									
1900	1							1	186
2000	1							1	186
2100									
2200									
2300									

Table A1.2

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

February

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	1							1	169
0100	1							1	169
0200									
0300									
0400									
0500									
0600	1							1	169
0700	1							1	169
0800									
0900									
1000	1							1	169
1100	1							1	169
1200	1							1	169
1300	1							1	169
1400									
1500	2							2	169
1600	3							3	169
1700	2							2	169
1800									
1900	1							1	169
2000	2							2	169
2100	2							2	169
2200	2							2	169
2300	1							1	169

Table A1.3

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

March

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	186
0100	3							3	186
0200	2							2	186
0300	1							1	186
0400	2							2	186
0500	3							3	186
0600	2							2	186
0700									
0800	2							2	186
0900	1	1						3	186
1000		1						2	186
1100	1	0	1					4	186
1200	2	0	1					5	186
1300	3	1						5	186
1400	3	1						5	186
1500	2	1						4	186
1600	4							4	186
1700	4	1						6	186
1800	4	1	1					9	186
1900	5	1	1					10	186
2000	2	1	1					7	186
2100	4	1						6	186
2200	5	1						7	186
2300	5							5	186

Table A1.4

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

April

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	180
0100									
0200									
0300									
0400									
0500	1							1	180
0600									
0700									
0800									
0900	1							1	180
1000	3							3	180
1100	1							1	180
1200	2							2	180
1300	3							3	180
1400	4							4	180
1500	7							7	180
1600	9							9	180
1700	5							5	180
1800	6							6	180
1900	3							3	180
2000	1							1	180
2100	1	1						3	180
2200	1	1						3	180
2300	1	1						3	180

Table A1.5

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

May

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	186
0100	2							2	186
0200	1							1	186
0300	1							1	186
0400	1							1	186
0500	2							2	186
0600	1							1	186
0700									
0800									
0900	2							2	186
1000	3							3	186
1100	4							4	186
1200	3							3	186
1300	8	1						10	186
1400	10	2						14	186
1500	9	2						13	186
1600	9	2	1					16	187*
1700	12	4	1					23	187*
1800	10	5						20	187*
1900	6	2						10	186
2000	9	1						11	186
2100	6							6	186
2200	7							7	186
2300	4							4	186

*Includes June 1

Table A1.6

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

June

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	180
0100	2							2	180
0200	2	1						4	180
0300	1	1						3	180
0400	1							1	180
0500	2							2	180
0600	1	1						3	181**
0700	1							1	180
0800	1							1	180
0900									
1000	2	2						6	180
1100	8	3	1					17	180
1200	12	4	1					23	180
1300	13	7	0	0	3			42	180
1400	16	7	0	0	2			40	180
1500	22	6	1					37	180
1600	16	4	3					33	179*
1700	17	4	1					28	179*
1800	12	5						22	179*
1900	15	3						21	180
2000	9	2						13	180
2100	8	1						10	180
2200	2							2	180
2300	2	1						4	180

*Counted in May **Includes July 1

Table A1.7

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

July

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	186
0100	2							2	186
0200	2							2	186
0300	1							1	186
0400	1							1	186
0500	1							1	186
0600									**
0700	1							1	186
0800	1							1	186
0900									
1000	5							5	186
1100	10							10	186
1200	11	4	2					25	186
1300	13	7	2	1				37	186
1400	13	4	6	1	1			48	186
1500	18	8	2	1	1	0	1	56	190#
1600	12	8	7	1	0	0	1	60	191*
1700	17	11	2	0	1			50	186
1800	17	5	1	2				38	186
1900	15	2	2					25	186
2000	12	2						16	186
2100	12							12	186
2200	6							6	186
2300	5							5	186

**Counted in June
#Includes 4 days of August
*Includes 5 days of August

Table A1.8

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

August

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	8							8	186
0100	7							7	186
0200	3	1						5	186
0300	1	1						3	186
0400	2							2	186
0500	2	2						6	186
0600	3	2						7	186
0700	3							3	186
0800									
0900	1							1	186
1000	5	1	1					10	186
1100	16	1	1					21	186
1200	14	4	2					28	186
1300	14	6						34	186
1400	17	4	3	1				38	186
1500	13	4	1	1	0	0	1	35	182#
1600	15	4	1	0	1			31	181*
1700	10	6	1	1				29	186
1800	12	4	1					23	186
1900	13	3						19	186
2000	11	1						13	186
2100	6	1						8	186
2200	6	1						8	186
2300	7							7	186

#4 days counted in July *5 days counted in July

Table A1.9

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

September

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2	1						4	180
0100	5							5	180
0200	2							2	180
0300									
0400	1							1	180
0500	4							4	180
0600	4							4	180
0700	6							6	180
0800	6	1						8	180
0900	10							10	180
1000	6							6	180
1100	7							7	180
1200	8	2						12	180
1300	10	0	1	1				17	180
1400	11	0	1	1				18	180
1500	8	5						23	180
1600	8	4	1					19	180
1700	12	1	2					20	180
1800	11	4	1					22	181**
1900	11	4						19	181**
2000	12							12	180
2100	7							7	180
2200	4	1						6	180
2300	2	1						4	180

**Includes October 1

Table A1.10

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

October

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000									
0100	2							2	186
0200	3							3	186
0300	5							5	186
0400	3							3	186
0500	2							2	186
0600									
0700									
0800									
0900	1							1	186
1000	2							2	186
1100	3							3	186
1200	5							5	186
1300	3							3	186
1400	2	1						4	186
1500	3	1						5	186
1600	7							7	186
1700	4	1						6	186
1800	4	1						6	185#
1900	4	1						6	185#
2000	1	1						3	186
2100	1							1	186
2200	1							1	186
2300	1							1	186

#1 day counted in September

Table A1.11

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

November

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000									
0100									
0200									
0300									
0400									
0500									
0600									
0700									
0800									
0900									
1000									
1100									
1200	1							1	180
1300	1							1	180
1400									
1500	1							1	180
1600	1							1	180
1700	2							2	180
1800	1							1	180
1900									
2000									
2100									
2200									
2300									

Table A1.12

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

December

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	1							1	186
0100									
0200									
0300									
0400									
0500									
0600									
0700									
0800	1							1	186
0900	1							1	186
1000	1							1	186
1100									
1200	1							1	186
1300									
1400									
1500									
1600									
1700									
1800									
1900									
2000									
2100	1							1	186
2200	1							1	186
2300	1							1	186

Table A1.13

Empirical Probability Occurrence of Thunderstorms

Cape Kennedy, Florida (1957 - 1962)

EST	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
00	*	.006	.011	.011	.011	.011	.011	.043	.022	*	*	.005	.011
01	*	.006	.016	*	.011	.011	.011	.038	.028	.011	*	*	.011
02	*	*	.011	*	.005	.022	.011	.029	.011	.016	*	*	.009
03	*	*	.005	*	.005	.017	.005	.016	*	.027	*	*	.006
04	.005	*	.011	*	.005	.006	.005	.011	.006	.016	*	*	.005
05	*	*	.016	.006	.011	.011	.005	.032	.022	.011	*	*	.010
06	*	.006	.011	*	.005	.017	*	.038	.022	*	*	*	.008
07	*	.006	*	*	*	.006	.005	.016	.033	*	*	*	.006
08	.005	*	.011	*	*	.006	.005	*	.044	*	*	.005	.006
09	.005	*	.016	.006	.011	*	*	.005	.056	.005	*	.005	.009
10	*	.006	.011	.017	.016	.033	.027	.054	.033	.011	*	.005	.018
11	*	.006	.022	.006	.022	.094	.054	.113	.039	.016	*	*	.031
12	*	.006	.027	.011	.016	.128	.134	.151	.067	.027	.006	.005	.048
13	*	.006	.027	.017	.054	.233	.199	.183	.094	.016	.006	*	.070
14	*	*	.027	.022	.075	.222	.258	.204	.100	.022	*	*	.078
15	*	.012	.022	.039	.070	.206	.295	.192	.128	.027	.006	*	.083
16	*	.018	.022	.050	.086	.184	.314	.171	.106	.038	.006	*	.083
17	*	.012	.032	.028	.128	.156	.269	.156	.111	.032	.011	*	.078
18	*	*	.048	.033	.107	.123	.204	.124	.122	.032	.006	*	.067
19	.005	.006	.054	.017	.054	.117	.134	.102	.105	.032	*	*	.052
20	.005	.012	.038	.006	.059	.072	.086	.070	.067	.016	*	*	.036
21	*	.012	.032	.017	.032	.056	.065	.043	.039	.005	*	.005	.026
22	*	.012	.038	.017	.038	.011	.032	.043	.033	.005	*	.005	.020
23	*	.006	.027	.017	.022	.022	.027	.038	.022	.005	*	.005	.016
Avg.	.001	.006	.022	.013	.035	.074	.090	.078	.055	.015	.002	.002	.033

*No thunderstorms observed

Table A1.14

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

Spring (March-April-May)

EST	Length of Sequences in Days							Total	N
	1	2	3	4	5	6	7	Occurrences	Count
0000	6							6	552
0100	5							5	552
0200	3							3	552
0300	2							2	552
0400	3							3	552
0500	6							6	552
0600	3							3	552
0700									
0800	2							2	552
0900	4	1						6	552
1000	5	1						7	552
1100	6	0	1					9	552
1200	7	0	1					10	552
1300	14	2						18	552
1400	17	3						23	552
1500	18	3						24	552
1600	22	2	1					29	553*
1700	21	5	1					34	553*
1800	20	6	1					35	553*
1900	14	3	1					23	552
2000	12	2	1					19	552
2100	11	2						15	552
2200	13	2						17	552
2300	10	1						12	552

*Includes 1 day from June

Table A1.15

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

Summer (June-July-August)

EST	Length of Sequences in Days							Total	N
	1	2	3	4	5	6	7	Occurrences	Count
0000	12							12	552
0100	11							11	552
0200	7	2						11	552
0300	3	2						7	552
0400	4							4	552
0500	5	2						9	552
0600	4	3						10	552
0700	5							5	552
0800	2							2	552
0900	1							1	552
1000	12	3	1					21	552
1100	34	4	2					48	552
1200	37	12	5					76	552
1300	40	20	2	3	3			113	552
1400	46	15	9	2	3			126	552
1500	53	18	4	2	1	0	2	128	552
1600	43	16	11	1	1	0	1	124	551*
1700	44	21	4	1	1			107	551*
1800	41	14	2	2				83	551*
1900	43	8	2					65	552
2000	32	5						42	552
2100	26	2						30	552
2200	14	1						16	552
2300	14	1						16	552

*1 day counted in May

Table A1.16

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

Fall (September-October-November)

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2	1						4	546
0100	7							7	546
0200	5							5	546
0300	5							5	546
0400	4							4	546
0500	6							6	546
0600	4							4	546
0700	6							6	546
0800	6	1						8	546
0900	11							11	546
1000	8							8	546
1100	10							10	546
1200	14	2						18	546
1300	14	0	1	1				21	546
1400	13	1	1	1				22	546
1500	12	6	0	0	1			29	546
1600	16	4	1					27	546
1700	18	2	2					28	546
1800	16	5	1					29	546
1900	15	5						25	546
2000	13	1						15	546
2100	8							8	546
2200	5	1						7	546
2300	3	1						5	546

Table A1.17

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957 - 1962)

Winter (December-January-February)

EST	Length of Sequences in Days							Total Occurrences	N Count
	1	2	3	4	5	6	7		
0000	2							2	541
0100	1							1	541
0200									
0300									
0400	1							1	541
0500									
0600	1							1	541
0700	1							1	541
0800	2							2	541
0900	2							2	541
1000	2							2	541
1100	1							1	541
1200	2							2	541
1300	1							1	541
1400									
1500	2							2	541
1600	3							3	541
1700	2							2	541
1800									
1900	2							2	541
2000	3							3	541
2100	3							3	541
2200	3							3	541
2300	2							2	541

Table A1.18

Empirical Probability Occurrence of Thunderstorms

Cape Kennedy, Florida (1957 - 1962)

EST	Spring	Summer	Fall	Winter	Annual
0000	.011	.022	.007	.004	.011
0100	.009	.020	.013	.002	.011
0200	.005	.020	.009	*	.009
0300	.004	.013	.009	*	.006
0400	.005	.007	.007	.002	.005
0500	.011	.016	.011	*	.010
0600	.005	.018	.007	.002	.008
0700	*	.009	.011	.002	.006
0800	.004	.004	.015	.004	.006
0900	.011	.002	.020	.004	.009
1000	.013	.038	.015	.004	.018
1100	.016	.087	.018	.002	.031
1200	.018	.138	.033	.004	.048
1300	.033	.205	.038	.002	.070
1400	.042	.228	.040	*	.078
1500	.043	.232	.053	.004	.083
1600	.052	.225	.049	.006	.083
1700	.061	.194	.051	.004	.078
1800	.063	.154	.053	*	.067
1900	.042	.118	.046	.004	.052
2000	.034	.076	.027	.006	.036
2100	.027	.054	.015	.006	.026
2200	.031	.029	.013	.006	.020
2300	.022	.029	.009	.004	.016
Average	.023	.081	.024	.003	.033

*No thunderstorms observed

Table A-2.1

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

4 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	January												
00-0359	0												186
04-0759	1												186
08-1159	1												186
12-1559	0												186
16-1959	1												186
20-2359	1												186
	February												
00-0359	1												169
04-0759	1												169
08-1159	1												169
12-1559	3												169
16-1959	4												169
[illegible]-2359	3												169
	March												
00-0359	3												186
04-0759	3												186
08-1159	2	0	1										186
12-1559	5	0	1										186
16-1959	9	1	1										186
20-2359	5	1	1										186

Table A 2.2

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

4 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	April												
00-0359	2												180
04-0759	1												180
08-1159	3												180
12-1559	10												180
16-1959	8	1											180
20-2359	2	1											180
	May												
00-0359	3												186
04-0759	2												186
08-1159	5												186
12-1559	15	2											186
16-1959	11	5	1	0	1								187
20-2359	10	2											186
	June												
00-0359	3	0	1										180
04-0759	2	1											181
08-1159	9	3	1										180
12-1559	18	8	2	1	2	1							180
16-1959	15	5	3	2	1								179
20-2359	10	2	1										180

Table A 2.3

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

4 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	July												
00-0359	4												186
04-0759	1												185
08-1159	9	1											186
12-1559	13	7	2	3	3	1	0	1					192
16-1959	11	8	6	2	0	1	2						191
20-2359	14	2											186
	August												
00-0359	9	1											186
04-0759	4	2											186
08-1159	16	2	1										186
12-1559	15	5	0	2	1	1	0	0	1				180
[illegible]-1959	20	5	2	0	0	1							181
[illegible]-2359	15	1											186
	September												
00-0359	4	1											180
04-0759	8												180
08-1159	13	2											180
12-1559	15	5	0	1	1								180
16-1959	12	3	3	1									181
20-2359	10	2											180

Table A 2.4

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

4 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	October												
00-0359	5												186
04-0759	3												186
08-1159	3												186
12-1559	7	2											186
16-1959	7	1											185
20-2359	2	1											186
	November												
00-0359	0												180
04-0759	0												180
08-1159	0												180
12-1559	2												180
[illegible]-1959	2												180
[illegible]-2359	0												180
	December												
00-0359	1												186
04-0759	0												186
08-1159	1												186
12-1559	1												186
16-1959	0												186
20-2359	1												186

Table A 2.5

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

Seasonal 4 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	Spring												
00-0359	8												552
04-0759	6												552
08-1159	10	0	1										552
12-1559	30	2	1										552
16-1959	28	7	2	0	1								553
20-2359	17	4	1										552
	Summer												
00-0359	16	1	1										552
04-0759	7	3											552
08-1159	34	6	2										552
12-1559	46	20	4	6	6	3	0	1	1				552
16-1959	46	18	11	4	1	2	2						551
20-2359	39	5	1										552
	Fall												
00-0359	9	1											546
04-0759	11												546
08-1159	16	2											546
12-1559	24	7	0	1	1								546
16-1959	21	4	3	1									546
20-2359	12	3											546
	Winter												
00-0359	2												541
04-0759	2												541
08-1159	3												541
12-1559	4												541
16-1959	5												541
20-2359	5												541

Table A 2.6

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

8 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	January												
00-0759	1												186
04-1159	2												186
08-1559	1												186
12-1959	1												186
16-2359	1												186
	February												
00-0759	2												169
04-1159	2												169
08-1559	4												169
12-1959	5												169
16-2359	5												169
	March												
00-0759	3												186
04-1159	4	0	1										186
08-1559	6	0	1										186
12-1959	12	1	1										186
16-2359	8	3	1										186
	April												
00-0759	3												180
04-1159	4												180
08-1559	8	2											180
12-1959	12	1											180
16-2359	9	2											180

Table A 2.7

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

8 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	May												
00-0759	5												186
04-1159	7												186
08-1559	17	2											186
12-1959	10	8	1	1	1								187
16-2359	15	5	1	0	1								187
	June												
00-0759	4	1	1										181
04-1159	9	2	1	1									181
08-1559	16	8	4	1	2	1							180
12-1959	14	6	4	4	1	1	1						179
16-2359	14	4	5	2	1								179
	July												
00-0759	5												185
04-1159	8	1											185
08-1559	13	7	2	3	3	1	0	1					192
12-1959	9	6	3	3	1	2	0	2	0	1	0	1	202
16-2359	12	8	6	2	0	1	2						191
	August												
00-0759	10	3											186
04-1159	18	4	0	1									186
08-1559	15	5	2	2	1	1	0	0	1				180
12-1959	15	8	3	2	1	2							174
16-2359	24	4	3	0	0	1							181

Table A 2.8

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

8 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	September												
00-0759	10	1											180
04-1159	15	3											180
08-1559	20	7	0	1	0	1							180
12-1959	12	4	6	0	1								178
16-2359	13	2	4	1									181
	October												
00-0759	6												186
04-1159	6												186
08-1559	7	2											186
12-1959	7	2	1										184
16-2359	8	1											185
	November												
00-0759	0												180
04-1159	0												180
08-1559	2												180
12-1959	4												180
16-2359	2												180
	December												
00-0759	1												186
04-1159	1												186
08-1559	2												186
12-1959	1												186
16-2359	1												186

Table A 2.9

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

Seasonal 8 Hour Periods

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	Spring												
00-0759	11												552
04-1159	15	0	1										552
08-1559	31	4	1										552
12-1959	34	10	2	1	1								553
16-2359	32	10	2	0	1								553
	Summer												
00-0759	19	4	1										552
04-1159	35	7	1	2									552
08-1559	44	20	8	6	6	3	0	1	1				552
12-1959	38	20	10	9	3	5	1	2	0	1	0	1	555
16-2359	50	16	14	4	1	2	2						551
	Fall												
00-0759	16	1											546
04-1159	21	3											546
08-1559	29	9	0	1	0	1							546
12-1959	23	6	7	0	1								542
16-2359	23	3	4	1									546
	Winter												
00-0759	4												541
04-1159	5												541
08-1559	7												541
12-1959	7												541
16-2359	7												541

Table A 2.10

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

Daily by Month

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
00-2359	January 3												186
00-2359	February 7	1											169
00-2359	March 9	6	1										187
00-2359	April 10	5											179
00-2359	May 10	8	2	1	1	1							187
00-2359	June 11	6	4	4	2	2	1						180
00-2359	July 9	6	4	3	1	2	0	2	0	1	0	1	203
00-2359	August 15	7	3	3	1	1	3						175
00-2359	September 12	8	5	2	0	1							175
00-2359	October 8	3	2										184
00-2359	November 4												180
00-2359	December 2	1											186

Table A 2.11

Total Occurrences of Thunderstorm Sequences of Exactly the Given Number of Days at Cape Kennedy, Florida (1957-1962)

Daily by Season

EST	Length of Sequences in Days												N Count
	1	2	3	4	5	6	7	8	9	10	11	12	
	Spring												
00-2359	29	19	3	1	1	1							553
	Summer												
00-2359	35	19	11	10	4	5	4	2	0	1	0	1	558
	Autumn												
00-2359	24	11	7	2	0	1							539
	Winter												
00-2359	12	2											541

Table A3.1

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-0359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	No occurrences											
February i=0	.006											
March i=0	.016											
April i=0	.011											
May i=0	.016											
June i=0	.033	.011	.006									
1	.333	.167										
2	.500											
July i=0	.022											
August i=0	.059	.005										
1	.091											
September i=0	.033	.006										
1	.167											
October i=0	.027											
November	No occurrences											
December i=0	.005											

(i given consecutive occurrences)

Table A3.2

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0400-0759 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	.005											
February i=0	.006											
March i=0	.016											
April i=0	.006											
May i=0	.011											
June i=0	.022	.006										
1	.250											
July i=0	.005											
August i=0	.043	.011										
1	.250											
eptember i=0	.044											
October i=0	.016											
November		No occurrences										
December		No occurrences										

(i given consecutive occurrences)

Table A3.3

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0800-1159 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January												
i=0	.005											
February												
i=0	.006											
March i=0	.027	.011	.005									
1	.400	.200										
2	.500											
April i=0	.017											
May i=0	.027											
June i=0	.100	.028	.006									
1	.278	.056										
2	.200											
July i=0	.059	.005										
1	.091											
August i=0	.124	.022	.005									
1	.174	.043										
2	.250											
September												
i=0	.094	.011										
1	.118											
October												
i=0	.016											
November	No occurrences											
December												
i=0	.005											

(i given consecutive occurrences)

Table A3.4

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January												
i=0	No occurrences											
February												
i=0	.018											
March i=0	.043	.011	.005									
1	.250	.125										
2	.500											
April i=0	.056											
May i=0	.102	.011										
1	.105											
June i=0	.333	.156	.078	.044	.022	.006						
1	.467	.233	.133	.067	.017							
2	.500	.286	.143	.036								
3	.571	.286	.071									
4	.500	.125										
5	.250											
July i=0	.385	.229	.141	.089	.047	.021	.010	.005				
1	.595	.365	.230	.122	.054	.027	.014					
2	.614	.386	.205	.091	.045	.023						
3	.630	.333	.148	.074	.037							
4	.529	.235	.118	.059								
5	.444	.222	.111									
6	.500	.250										
7	.500											
August												
i=0	.294	.156	.100	.072	.044	.028	.017	.011	.006			
1	.528	.340	.245	.151	.094	.057	.038	.019				
2	.643	.464	.286	.179	.107	.071	.036					
3	.722	.444	.278	.167	.111	.056						
4	.615	.385	.231	.154	.077							
5	.625	.375	.250	.125								
6	.600	.400	.200									
7	.667	.333										
8	.500											

(i given consecutive occurrences)

Table A3.4 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
September												
i=0	.189	.067	.028	.017	.006							
1	.353	.147	.088	.029								
2	.417	.250	.083									
3	.600	.200										
4	.333											
October												
i=0	.059	.011										
1	.182											
November												
i=0	.011											
December												
i=0	.005											

(i given consecutive occurrences)

Table A3.5

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1600-1959 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January												
i=0	.005											
February												
i=0	.024											
March i=0	.075	.016	.005									
1	.214	.071										
2	.333											
April i=0	.056	.006										
1	.100											
May i=0	.155	.059	.021	.011	.005							
1	.379	.138	.069	.034								
2	.364	.182	.091									
3	.500	.250										
4	.500											
June i=0	.263	.117	.056	.022	.006							
1	.447	.213	.085	.021								
2	.476	.190	.048									
3	.400	.100										
4	.250											
July i=0	.382	.225	.126	.068	.042	.026	.010					
1	.589	.329	.178	.110	.068	.027						
2	.558	.302	.186	.116	.047							
3	.542	.333	.208	.083								
4	.615	.385	.154									
5	.625	.250										
6	.400											
August i=0	.232	.077	.033	.017	.011	.006						
1	.333	.143	.071	.048	.024							
2	.429	.214	.143	.071								
3	.500	.333	.167									
4	.667	.333										
5	.500											

(i given consecutive occurrences)

Table A3.5 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1600-1959 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
September												
i=0	.171	.066	.028	.006								
1	.387	.161	.032									
2	.417	.083										
3	.200											
October												
i=0	.049	.005										
1	.111											
November												
i=0	.011											
December	No occurrences											

(i given consecutive occurrences)

Table A3.6

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

2000-2359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	.005											
February i=0	.018											
March i=0	.054	.016	.005									
1	.300	.100										
2	.333											
April i=0	.022	.006										
1	.250											
May i=0	.075	.011										
1	.143											
June i=0	.094	.022	.006									
1	.235	.059										
2	.250											
July i=0	.097	.011										
1	.111											
August i=0	.091	.005										
1	.059											
September i=0	.078	.011										
1	.143											
October i=0	.022	.005										
1	.250											
November	No occurrences											
December i=0	.005											

(i given consecutive occurrences)

Table A3.7

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-0359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Spring i=0	.014											
Summer i=0	.038	.005	.002									
1	.143	.048										
2	.333											
Autumn i=0	.020	.002										
1	.091											
Winter i=0	.004											
0400-0759 EST												
Spring i=0	.011											
Summer i=0	.024	.005										
1	.231											
Autumn i=0	.020											
Winter i=0	.004											
0800-1159 EST												
Spring i=0	.024	.004	.002									
1	.154	.077										
2	.500											
Summer i=0	.094	.018	.004									
1	.192	.038										
2	.200											
Autumn i=0	.037	.004										
1	.100											
Winter i=0	.005											

(i given consecutive occurrences)

Table A3.7 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Spring i=0	.067	.007	.002									
1	.108	.027										
2	.250											
Summer i=0	.339	.181	.107	.069	.038	.018	.009	.005	.002			
1	.535	.316	.203	.112	.053	.027	.016	.005				
2	.590	.380	.210	.100	.050	.030	.010					
3	.644	.356	.169	.085	.051	.017						
4	.553	.263	.132	.079	.026							
5	.476	.238	.143	.048								
6	.500	.300	.100									
7	.600	.200										
8	.333											
Autumn i=0	.086	.026	.009	.005	.002							
1	.298	.106	.064	.021								
2	.357	.214	.071									
3	.600	.200										
4	.333											
Winter i=0	.007											
1600-1959 EST												
Spring i=0	.096	.027	.009	.004	.002							
1	.283	.094	.038	.019								
2	.333	.133	.067									
3	.400	.200										
4	.500											
Summer i=0	.294	.142	.073	.036	.020	.011	.004					
1	.481	.247	.123	.068	.037	.012						
2	.513	.256	.141	.077	.026							
3	.500	.275	.150	.050								
4	.550	.300	.100									
5	.545	.182										
6	.333											
Autumn i=0	.077	.024	.009	.002								
1	.310	.119	.024									
2	.385	.077										
3	.200											
Winter i=0	.009											

(i given consecutive occurrences)

Table A3.7 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

2000-2359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Spring i=0	.051	.011	.002									
1	.214	.036										
2	.167											
Summer i=0	.094	.013	.002									
1	.135	.019										
2	.143											
Autumn i=0	.033	.005										
1	.167											
Winter i=0	.009											

(i given consecutive occurrences)

Table A3.8

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-0759 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	.005											
February i=0	.012											
March i=0	.016											
April i=0	.017											
May i=0	.027											
June i=0	.050	.017	.006									
1	.333	.111										
2	.333											
July i=0	.027											
August i=0	.086	.016										
1	.188											
September i=0	.067	.006										
1	.083											
October i=0	.032											
November	No occurrences											
December i=0	.005											

(i given consecutive occurrences)

Table A3.9

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0400-1159 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January												
i=0	.011											
February												
i=0	.012											
March i=0	.038	.011	.005									
1	.286	.143										
2	.500											
April i=0	.022											
May i=0	.038											
June i=0	.110	.039	.017	.006								
1	.350	.150	.050									
2	.429	.143										
3	.333											
ly i=0	.054	.005										
1	.100											
August i=0	.161	.038	.011	.005								
1	.233	.067	.033									
2	.286	.143										
3	.500											
September												
i=0	.117	.017										
1	.143											
October												
i=0	.032											
November	No occurrences											
December												
i=0	.005											

(i given consecutive occurrences)

Table A3.10

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0800-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	.005											
February i=0	.024											
March i=0	.048	.011	.005									
1	.222	.111										
2	.500											
April i=0	.067	.011										
1	.167											
May i=0	.113	.011										
1	.095											
June i=0	.356	.178	.089	.044	.022	.006						
1	.500	.250	.125	.063	.016							
2	.500	.250	.125	.031								
3	.500	.250	.063									
4	.500	.125										
5	.250											
July i=0	.385	.229	.141	.089	.047	.021	.010	.005				
1	.595	.365	.230	.122	.054	.027	.014					
2	.614	.386	.205	.091	.045	.023						
3	.630	.333	.148	.074	.037							
4	.529	.235	.118	.059								
5	.444	.222	.111									
6	.500	.250										
7	.500											
August i=0	.328	.178	.111	.072	.044	.028	.017	.011	.006			
1	.542	.339	.220	.136	.085	.051	.034	.017				
2	.625	.406	.250	.156	.094	.063	.031					
3	.650	.400	.250	.150	.100	.050						
4	.615	.385	.231	.154	.077							
5	.625	.375	.250	.125								
6	.600	.400	.200									
7	.667	.333										
8	.500											

(i given consecutive occurrences)

Table A3.10 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0800-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
September												
i=0	.244	.083	.033	.022	.011	.006						
1	.341	.136	.091	.045	.023							
2	.400	.267	.133	.067								
3	.667	.333	.167									
4	.500	.250										
5	.500											
October												
i=0	.059	.011										
1	.182											
November												
i=0	.011											
December												
i=0	.011											

(i given consecutive occurrences)

Table A3.11

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1959 EST		k additional consecutive occurrences											
		1	2	3	4	5	6	7	8	9	10	11	12
January	i=0	.005											
February	i=0	.030											
March	i=0	.091	.016	.005									
	1	.176	.059										
	2	.333											
April	i=0	.078	.006										
	1	.071											
May	i=0	.203	.091	.032	.016	.005							
	1	.447	.158	.079	.026								
	2	.353	.176	.059									
	3	.500	.167										
	4	.333											
June	i=0	.402	.229	.134	.073	.034	.017	.006					
	1	.569	.333	.181	.083	.042	.014						
	2	.585	.317	.146	.073	.024							
	3	.542	.250	.125	.042								
	4	.462	.231	.077									
	5	.500	.167										
	6	.333											
July	i=0	.480	.342	.248	.183	.134	.099	.069	.050	.030	.020	.010	.005
	1	.711	.515	.381	.278	.206	.144	.103	.062	.041	.021	.010	
	2	.725	.536	.391	.290	.203	.145	.087	.058	.029	.014		
	3	.740	.540	.400	.280	.200	.120	.080	.040	.020			
	4	.730	.541	.378	.270	.162	.108	.054	.027				
	5	.741	.519	.370	.222	.148	.074	.037					
	6	.700	.500	.300	.200	.100	.050						
	7	.714	.429	.286	.143	.071							
	8	.600	.400	.200	.100								
	9	.667	.333	.167									
	10	.500	.250										
	11	.500											

(i given consecutive occurrences)

Table A3.11 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1959 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
August i=0	.374	.195	.103	.057	.029	.011						
1	.523	.277	.154	.077	.031							
2	.529	.294	.147	.059								
3	.556	.278	.111									
4	.500	.200										
5	.400											
September												
i=0	.242	.112	.051	.011	.006							
1	.465	.209	.047	.023								
2	.450	.100	.050									
3	.222	.111										
4	.500											
October												
i=0	.076	.022	.005									
1	.286	.071										
2	.250											
November												
i=0	.022											
December												
i=0	.005											

(i given consecutive occurrences)

Table A3.12

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1600-2359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January i=0	.005											
February i=0	.030											
March i=0	.091	.027	.005									
1	.294	.059										
2	.200											
April i=0	.072	.011										
1	.154											
May i=0	.176	.059	.021	.011	.005							
1	.333	.121	.061	.030								
2	.364	.182	.091									
3	.500	.250										
4	.500											
June i=0	.279	.134	.067	.022	.006							
1	.480	.240	.080	.020								
2	.500	.167	.042									
3	.333	.083										
4	.250											
July i=0	.387	.225	.126	.068	.042	.026	.010					
1	.581	.324	.176	.108	.068	.027						
2	.558	.302	.186	.116	.047							
3	.542	.333	.208	.083								
4	.615	.385	.154									
5	.625	.250										
6	.400											
August i=0	.260	.083	.039	.017	.011	.006						
1	.319	.149	.064	.043	.021							
2	.467	.200	.133	.067								
3	.429	.286	.143									
4	.667	.333										
5	.500											

(i given consecutive occurrences)

Table A3.13

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-0759 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Spring i=0	.020											
Summer i=0	.054	.011	.002									
1	.200	.033										
2	.167											
Autumn i=0	.033	.002										
1	.056											
Winter i=0	.007											
0400-1159 EST												
Spring i=0	.033	.004	.002									
1	.111	.056										
2	.500											
Summer i=0	.109	.027	.009	.004								
1	.250	.083	.033									
2	.333	.133										
3	.400											
Autumn i=0	.049	.005										
1	.111											
Winter i=0	.009											
0800-1559 EST												
Spring i=0	.076	.011	.002									
1	.143	.024										
2	.167											

(i given consecutive occurrences)

Table A3.13 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0800-1559 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Summer i=0	.357	.196	.114	.069	.038	.018	.009	.005	.002			
1	.548	.320	.193	.107	.051	.025	.015	.005				
2	.583	.352	.194	.093	.046	.028	.009					
3	.603	.333	.159	.079	.048	.016						
4	.553	.263	.132	.079	.026							
5	.476	.238	.143	.048								
6	.500	.300	.100									
7	.600	.200										
8	.333											
Autumn i=0	.104	.031	.011	.007	.004	.002						
1	.298	.105	.070	.035	.018							
2	.353	.235	.118	.059								
3	.667	.333	.167									
4	.500	.250										
5	.500											
Winter i=0	.013											
1200-1959 EST												
Spring i=0	.132	.042	.013	.005	.002							
1	.315	.096	.041	.014								
2	.304	.130	.043									
3	.429	.143										
4	.333											
Summer i=0	.422	.259	.166	.108	.068	.045	.027	.018	.011	.007	.004	.002
1	.615	.393	.256	.162	.107	.064	.043	.026	.017	.009	.004	
2	.639	.417	.264	.174	.104	.069	.042	.028	.014	.007		
3	.652	.413	.272	.163	.109	.065	.043	.022	.011			
4	.633	.417	.250	.167	.100	.067	.033	.017				
5	.658	.395	.263	.158	.105	.053	.026					
6	.600	.400	.240	.160	.080	.040						
7	.667	.400	.267	.133	.067							
8	.600	.400	.200	.100								
9	.667	.333	.167									
10	.500	.250										
11	.500											
Autumn i=0	.113	.044	.018	.004	.002							
1	.393	.164	.033	.016								
2	.417	.083	.042									
3	.200	.100										
4	.500											

(i given consecutive occurrences)

Table A3.13 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

1200-1959 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
Winter i=0	.013											
1600-2359 EST												
Spring i=0	.114	.033	.009	.004	.002							
1	.286	.079	.032	.016								
2	.278	.111	.056									
3	.400	.200										
4	.500											
Summer i=0	.310	.149	.078	.036	.020	.011	.004					
1	.480	.251	.117	.064	.035	.012						
2	.524	.244	.134	.073	.024							
3	.465	.256	.140	.047								
4	.550	.300	.100									
5	.545	.182										
6	.333											
Autumn i=0	.082	.026	.011	.002								
1	.311	.133	.022									
2	.429	.071										
3	.167											
Winter i=0	.013											

(i given consecutive occurrences)

Table A3.14

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-2359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
January												
i=0	.016											
February												
i=0	.053	.006										
1	.111											
March i=0	.128	.043	.005									
1	.333	.042										
2	.125											
April i=0	.112	.028										
1	.250											
May i=0	.251	.128	.059	.032	.016	.005						
1	.511	.234	.128	.064	.021							
2	.458	.250	.125	.042								
3	.545	.273	.091									
4	.500	.167										
5	.333											
June i=0	.444	.278	.172	.100	.050	.022	.006					
1	.625	.388	.225	.113	.050	.013						
2	.620	.360	.180	.080	.020							
3	.581	.290	.129	.032								
4	.500	.222	.056									
5	.444	.111										
6	.250											
July i=0	.493	.350	.251	.182	.133	.099	.069	.049	.030	.020	.010	.005
1	.710	.510	.370	.270	.200	.140	.100	.060	.040	.020	.010	
2	.718	.521	.380	.282	.197	.141	.085	.056	.028	.014		
3	.725	.529	.392	.275	.196	.118	.078	.039	.020			
4	.730	.541	.378	.270	.162	.108	.054	.027				
5	.741	.519	.370	.222	.148	.074	.037					
6	.700	.500	.300	.200	.100	.050						
7	.714	.429	.286	.143	.071							
8	.600	.400	.200	.100								
9	.667	.333	.167									
10	.500	.250										
11	.500											

(i given consecutive occurrences)

Table A3.14 (cont)

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-2359 EST	k additional consecutive occurrences											
	1	2	3	4	5	6	7	8	9	10	11	12
August i=0	.469	.280	.177	.114	.069	.040	.017					
1	.598	.378	.244	.146	.085	.037						
2	.633	.408	.245	.143	.061							
3	.645	.387	.226	.097								
4	.600	.350	.150									
5	.583	.250										
6	.429											
September												
i=0	.326	.166	.074	.029	.011	.006						
1	.509	.228	.088	.035	.018							
2	.448	.172	.069	.034								
3	.385	.154	.077									
4	.400	.200										
5	.500											
October												
i=0	.109	.038	.011									
1	.350	.100										
2	.286											
November												
i=0	.022											
December												
i=0	.022	.005										
1	.250											

(i given consecutive occurrences)

Table A3.15

Empirical Conditional Probability of Thunderstorm Occurrence

Cape Kennedy, Florida (1957 - 1962)

0000-2359 EST		k additional consecutive occurrences											
		1	2	3	4	5	6	7	8	9	10	11	12
Spring	i=0	.165	.067	.022	.011	.005	.002						
	1	.407	.132	.066	.033	.011							
	2	.324	.162	.081	.027								
	3	.500	.250	.083									
	4	.500	.167										
	5	.333											
Summer	i=0	.470	.305	.203	.134	.086	.056	.032	.018	.011	.007	.004	.002
	1	.649	.431	.286	.183	.118	.069	.038	.023	.015	.008	.004	
	2	.665	.441	.282	.182	.106	.059	.035	.024	.012	.006		
	3	.664	.425	.274	.159	.088	.053	.035	.018	.009			
	4	.640	.413	.240	.133	.080	.053	.027	.013				
	5	.646	.375	.208	.125	.083	.042	.021					
	6	.581	.323	.194	.129	.065	.032						
	7	.556	.333	.222	.111	.056							
	8	.600	.400	.200	.100								
	9	.667	.333	.167									
	10	.500	.250										
	11	.500											
Autumn	i=0	.150	.067	.028	.009	.004	.002						
	1	.444	.185	.062	.025	.012							
	2	.417	.139	.056	.028								
	3	.333	.133	.067									
	4	.400	.200										
	5	.500											
Winter	i=0	.030	.004										
	1	.125											

(i given consecutive occurrences)

Table A4.1

Frequency Distribution of Maximum Wind Speeds

Observed with Thunderstorms at Cape Kennedy, Florida (1957-1962)

0000-2359 EST	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
19-24 kt		1	5	3	10	15	20	18	13	2	1	
25-27 kt	1	1	3	1	2	5	6	5	3			
28-31 kt	1	2	4	2	1	4	6	6	5			
32-46 kt		1	3	4	4	8	5	5	5	1		
1200-1959 EST												
≤ 9 kt						14	7	22				
10-11 kt						11	8	6				
12-14 kt						11	18	12				
15-18 kt						9	13	10				
19-24 kt						12	19	14				
25-27 kt						5	6	5				
28-31 kt						4	5	4				
32-46 kt						7	5	4				

APPENDIX B

Testing Procedure for Order for Markov Chains

Adotevi-Akue et al [1] have shown that the appropriate forms of the asymptotically Chi-square statistic as derived by Billingsley [2] for testing the order of Markov chains (with two states and 4-day sequences) are:

For zero order,

$$\chi^2 = \sum_{a_1 \ldots a_4} \frac{(f_{a_1 \ldots a_4} - \frac{f_{a_1 \ldots a_3} f_{a_4}}{N})^2}{\frac{f_{a_1 \ldots a_3} f_{a_4}}{N}}$$

with 7 degrees of freedom where the f's are the sequence frequencies and N is the total number of transitions.

For first order,

$$\chi^2 = \sum_{a_1 \ldots a_4} \frac{(f_{a_1 \ldots a_4} - \frac{f_{a_1 \ldots a_3} f_{a_3 a_4}}{f_{a_3}})^2}{\frac{f_{a_1 \ldots a_3} f_{a_3 a_4}}{f_{a_3}}}$$

with 6 degrees of freedom.

For second order,

$$\chi^2 = \sum_{a_1 \ldots a_4} \frac{(f_{a_1 \ldots a_4} - \frac{f_{a_1 \ldots a_3} f_{a_2 \ldots a_4}}{f_{a_2 a_3}})^2}{\frac{f_{a_1 \ldots a_3} f_{a_2 \ldots a_4}}{f_{a_2 a_3}}}$$

with 4 degrees of freedom.

Degrees of freedom are determined by the relation

$$df = (S^{t+1} - S^t) - (S^{r+1} - S^r)$$

where S is the number of outcome, t is the number of days in the sequence minus one and r is the order of the model.

Sample Calculations of Chi-square

The following frequencies were extracted from 6 years, 1957-1962, of data at Cape Kennedy, Florida for the summer season. The time period is 1200 - 1959 EST. The 4-day sequences beginning on each day of the summer period were tabulated yielding a total of 552 frequencies for the 6-year period.

Sequence	Frequency	Sequence	Frequency
NNNN	138	TNNN	38
NNNT	37	TNNT	20
NNTN	23	TNTN	12
NNTT	33	TNTT	19
NTNN	22	TTNN	37
NTNT	16	TTNT	15
NTTN	20	TTTN	31
NTTT	32	TTTT	59

The letter "T" denotes thunderstorm occurrence and "N" non-occurrence.

If it is desired to test the above sequences for first order the appropriate statistic would be summed over the 16 sequences. For example, if we denote Δ as the centributum of each individual sequence to the total Chi-square, the Δ value for the first sequence (NNNN) would be:

$$\Delta = \frac{\left(138 - \frac{(175)(235)}{323}\right)^2}{\frac{(175)(235)}{323}} = 0.895526$$

where

$$fa_1 \ldots a_4 = 138;\ fa_1 \ldots a_3 = 175;\ fa_3 a_4 = 235;\ fa_3 = 323$$

The Chi-square value is,

$$\chi^2 = \sum_{i=1}^{16} \Delta i = 9.82338$$

The null hypothesis tested is that within the assumption that the process is Markovian, the order of dependence is one. Interpretation as to the significance of the above Chi-square value cannot be made until the results of the zero and second order tests can be evaluated.

Bibliography

1. Adotevi-Akue, G. M., et al, "Evaluation of Alternative Markovian Models for Precipitation Occurrence in Oregon," Oregon State University, Progress Report to the Technical Committee, Regional Research Project W-48, May 1965, 29 pp.

2. Billingsley, P., "Statistical Methods in Markov Chains," Annals of Mathematical Statistics, Vol. 32, No. 1, Mar. 1961, pp. 12-40.